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(Selected Articles)

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Variable Sweep Wing Aircraft

Tseng Ju-chang

For solving the contradiction between high altitude flight and low altitude flight; improving the property of aircraft in taking off and landing; and for broadening the scope of using aircrafts, an effective way has been found. That is the successful engineering of variable sweep wing aircraft. Although it has some shortcomings, the prospect of this kind of aircraft, as proved by fact, is definitely very promising. Here we try to make a brief introduction of its development, strong points and shortcomings.

Subduing Resistance and Improving Flight Velocity

Ever since the advent of aircraft, people have tried by every possible means to improve its flight velocity. First , some measures have been taken to change the external form of aircrafts, such as changing the double or multi-plane wing into single plane wing, and removing the bracing wire support. Those that cannot be removed have been changed. The cabin and antenna, for example,have become streamlined, the surface cloth cover has been replaced with metal cover. The outward appearance has thereby become more smooth. All these measures have effectively improved the aerodynamical out form and greatly reduced the resistance of aircrafts. Consequently, the flight velocity has been remarkedly promoted.

Before World War 11, through every kind of effort , the flight velocity was made to reach 700 km per hour. It seemed hardly possible to make the aircrafts fly any faster.

When jet engine was brough into being, the aviation technology had a new chance to make rapid development. The flight velocity was tremendously increased when an aircraft was equipped with a jet engine even without any change of its outward appearance. But when the flight velocity was close to the sound speed, it stopped increasing any more, and the control of the aircraft became difficult, too. Thus the flight velocity was confined within the range of sound speed and there seemed to be no way to go beyond this limit. This is the so-called "sound barrier"

Breaking the "sound barrier" to achieve supersonic flight velocity then came to be a great challenge in aviation science.

As a matter of fact, when the flight velocity is close to sound speed, the speed of some part on the surface of the wing has become supersonic, and it forms a lambda-type (λ) shock wave on the wing surface (see Figure 1). This shock wave brings a sudden increase of the aircraft resistance. Because of the acceleration of the flight velocity, the position of the lambda wave begins to move. Consequently, not only the resistane has increased, the control of the aircraft has also become difficult because the aircraft continues to climb and to fall intermittently.

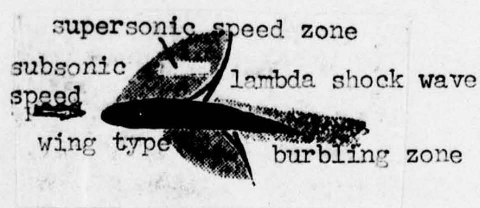


Figure 1 Lambda shock wave

To make the wing back swept, the flight velocity can go beyond the so-called "sound barrier". The back swept wing can delay the production of

shock wave, because only the size of speed volume perpendicular to the front edge of the wing can determine whether there is shock wave on the wing surface (see Figure 4). If the flight Mach number is 0.7, there will be shock wave on the wing. If the wing is back swept by 50°, there can only be shock wave on the back swept wing when the flight Mach number is 1.09 At the time when the flight Mach number is 1.09, the speed volume perpendicular to the back swept wing is 0.7 (the degree of perpendicular = flight Mach number x COS50°). In fact, before the flight Mach number becomes 1.09, there has been shock wave on the wing.

To sweep the wing backward not only delays the production of shock wave, but it also reduces the aircraft resistance even if there is still shock wave. The resistance on the back swept wing can be completely overcome by thrust of the engine, so the aircraft can accelerate its velocity and make the velocity pass over the sound speed.

The greater the angle of back swept is, the longer the delay of shock wave production and the smaller the shock wave resistance. So, for the purpose of reducing the wave resistance and promoting flight velocity, the back swept angle should be greater, and at the same time, the aspect ratio of the wing should be made smaller. It is better to have symmetrical wings and the wings must be as thin as possible.

The Contradiction Between High and Low Altitude Flight

In the process of taking off and landing, in order to reduce the runway length and to guarantee the safty in taking-off and landing, the

speed of taking-off and landing is the smaller the better. For an aircraft of small velocity, the back swept angle is small and the aspect ratio is large. The relative thickness of the airfoil section and the bending are all great.

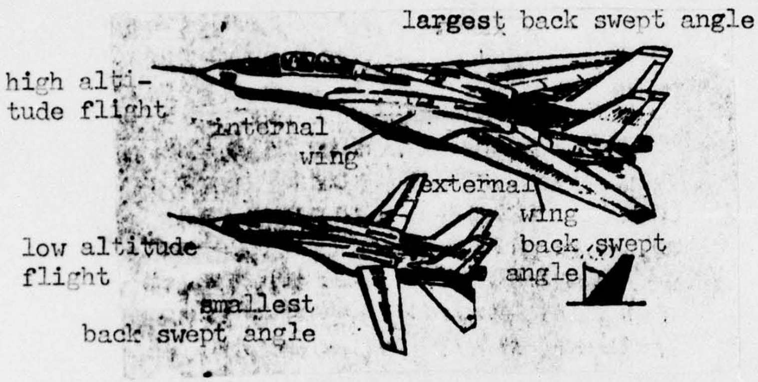


Figure 2 Situation of high-speed and low-speed flight of a certain type of aircraft

To use general lift-stengthening device (such as trailing-edge flap) will be easy to have low taking-off and landing speed. For a supersonic aircraft, because the back swept angle is large and the aspect ratio is small, the relative thickness of airfoil section and the relative bending are all small, to have low taking-off and landing speed, besides the general lift-strengthening device, the incidence angle of the wing must be made larger. But the aircraft will lift its head very high when it is taking off or landing, and the pilot's vision will be blocked. Also the landing gear must be very large (see Figure 3), otherwise, the runway must be very long. So far as the taking-off and landing are concerned, , the back swept angle is the smaller the better, but the aspect ratio, relative thickness and relative bending are all required to be large. So the requirements of the outward appearance of an aircraft for promoting its flight velocity and for reducing

its speed of taking-off and landing are contradictory. As a consequence of the promoting of flight velocity, the back swept angle has been made larger and the sapect aspect ratio, relative thickness and bending are reduced. Obviously, the requirements of the outward appearance of an aircraft for high flight velocity and low speed of taking-off and landing become more and more contradictory. In order to solve such a contradiction, a variable sweep wing aircraft has been brought into being. This kind of aircraft can meet the requirement for both the supersonic flight (large back swept angle) and the low speed flight, taking-off and landing.

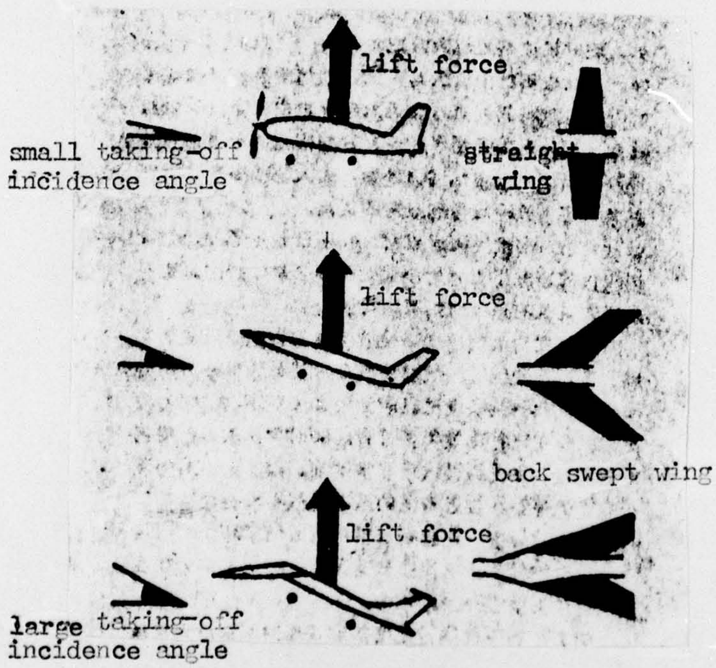


Figure 3 The relationship between back swept angle and taking-off incidence angle at same speed

Characteristics of Variable Sweep Wing Aircraft

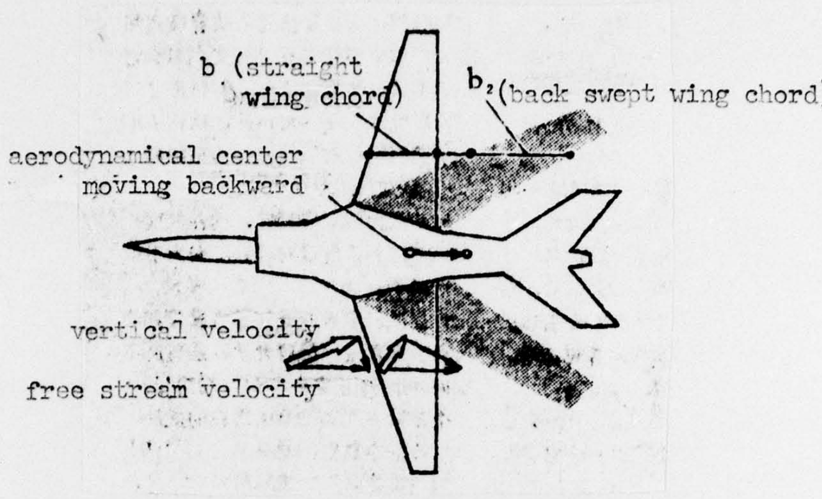
The merits of using variable sweep wing are as follows:

1. An aircraft with variable sweep wings can adapt to different

flight velocity scales. An aircraft with a fixed back swept angle, for satisfying the requirements for both high velocity flight and low speed taking-off and landing, cannot but make a compromise. The high velocity flight must be made at the expense of low speed taking off and landing or the other way round. But an aircraft with variable sweep wings can use different back swept angle at different speed and it can have maximum lift-drag ratio with any speed. This means that the aircraft can minimize resistance under the condition that the lift force remains unchanged at different speed. It can further satisfy the requirement for best flight performance in different speed

2. It can reduce the speed in taking-off and landing and also shorten the taxying distance. An aircraft with a fixed back swept wing must have a larger incidence angle if it wants to have low speed for taking-off and landing. Thus the head of the aircraft must lift very high and the undercarriages are also very big. If it is a variable sweep wing aircraft, it can make the landing incidence angle smaller only by reducing its back swept angle, and at the same time, its aspect ratio and wing arae are enlarged, and so are the relative thickness and relative bending of the wing (see Figure 4). All these are good for reducing the taking-off and landing speed and shorten the taxying distance.

3. In order to escape radar scanning, a supersonic aircraft is required able to fly at low altitude below 300 meters. Then will come two problems: One is that because altitude is low, the air density is great, so it will have greater resistance than the flight of same Mach number in high altitude. For reducing the resistance of low altitude supersonic flight, it requires



Fifure 4 Effect of variable back sweep angle on partial parameter

the wing to have larger back swept angle and smaller aspect ratio. The other problem is that because of the sudden wind formed by air convection in the low altitude, the aircraft will begin shaking and it is easy to make the pilots feel tired. The shaking can also affect accuracy of weapons as well as the structure of the aircraft. The larger the back swept angle is, and the smaller the aspect ratio is, the smaller of the wind effect will be on the aircraft. When a variable sweep wing is making a low altitude supersonic flight, it can sweep back to the largest back sweep angle. Thus it can reduce the low altitude resistance and lessen the effect of the wind on the aircraft. Consequently, low altitude supersonic flight becomes more suitable.

One main characteristic of variable sweep wing aircraft is that it can change the outward appearance of its own, and use the good points of supersonic and subsonic aircrafts to complete various kinds of mission. As a variable sweep wing aircraft has small resistance, its climbing time and acceleration time are all short, so its maneuverability is good. In

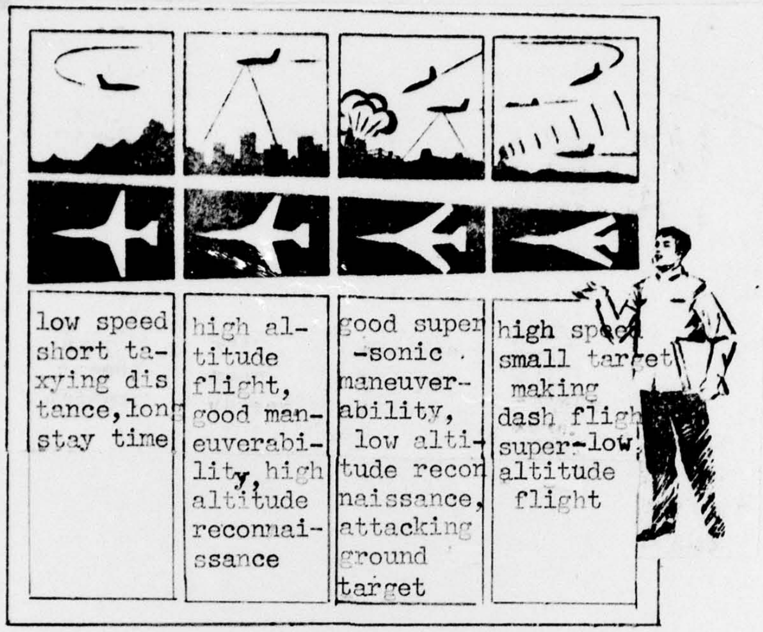


Figure 5 The merits and uses of variable sweep wing aircraft

addition, making a defense patrol, a variable sweep wing aircraft has more stay time to make continuous flight. In designing a fighter, which is required to be able to directly support the ground troop in the front, to attack ground target behind enemy line, to complete low altitude subsonic and high altitude supersonic reconnaissance flight and to achieve air supremacy, a variable sweep wing aircraft can be the best to carry out these missions. For supporting ground troop in the front, the main task a fighter should be able to perform is to scan and to destroy enemy target in the front. It can use a small back swept angle to make subsonic flight ($M = 0.5 \sim 0.7$), and in the front it can have long stay time. When it is necessary, it can use large back swept angle to make supersonic flight to trail and attack enemy targets. It can escape from the enemy aircrafts in the air, and can also make transonic and supersonic flights in low altitude by using large back swept angle to

penetrate into areas behind the enemy. It can achieve air supremacy when it uses the maximum back swept angle to fly within the supersonic scale ($M = 2 \sim 2.5$). So a single variable sweep wing aircraft can carry out many different missions (see Figure 5).

There are some difficulties in using variable sweep wing. The major one is that when aircraft changes swwep angle, the position of its center of gravity will follow to change and so is the application point of lift force (see Figure 4). The position of center of gravity and the application position of lift force of an aircraft all have their definite requirements. When the change scale of the wing sweep angle is large, the position of the center of gravity and the application position of lift force are prone to change, and as a reult, the control of the aircraft becomes difficult. For solving such a problem, many of the variable sweep wing aircrafts are made possible to change the sweep angle of the outer wings only. Thus the weight and lift force acting on the outer wings which can be back swept constitute only a part of the total weight and lift force of an aircraft. When the back sweep angle is changing, the change of the center of gravity and the application position of lift firce of the whole aircraft will be very small. In order to compenaste the movement of the center of gravity and the application position of lift force caused by the change of back sweep angle, some aircrafts have been equipped with a fuel transporting system to regulate the fuel consumption schedule.When the wings are changing to back swept, the fuel transporting schedule and speed are controlled by a gravity computer.

In addition, the structure of a variable sweep wing aircraft is

very expensive. To change a fixed wing into a movable one is no easy task. The structure is complicated and the requirements of quality of materials are high, and all these will increase the weight of an aircraft. Moreover, because of the constant change of the sweep angle to meet different requirements, the control of an aircraft undoubtedly becomes more complicated and difficult. Fortunately, as the aviation science is advanced day by day, all of these problems can be solved gradually.

(Drawing by Wen Cheng-cheng)

The Flight of Pilotless Aircraft (2)

Lu Wen

The article "The Flight of Pilotless Aircarft" in June Issue this year of this journal gave a description of the flight of pilotless aircraft, and the flight was divided into three stages: the beginning of flight, the stage of carrying out missions and the conclusion of flight. Without doubt, the stage of carrying out missions is the most important stage of flight. The success or failure of flight at this stage will directly affect the outcomes of the mission, and what affects the flight is the way of navigation. This article now will concentrate to deal with navigation.

When a pilotless aircraft has climbed to the predetermined flight altitude, through distance control instruction or program control instruction, it will change to a level steady altitude flight and be guided to an assigned area, then it begins to carry out its mission. This is an important flight stage of a pilotless aircraft. The ways of navigation for a pilotless aircraft flight to carry out its mission, according to the different nature of the mission, are of many different kinds. There are two which are now used most frequently.

1. Radio Distance Control Guidance

Usually in the process of carrying out its mission, a pilotless aircraft will not enter into enemy's territorial space. If it is necessary, it flies there for only a short while. When an aircraft is within the function range of our own radar and distance control station, this way of navigation is adoptable. The target aircraft, and most of the distance

controlled mini-flying vehicles, for example, can all be guided by distance control instruction.

Figure 1 is a sketch diagram of construction and principles of a whole navigation system. The whole system is composed of ground and airborne two

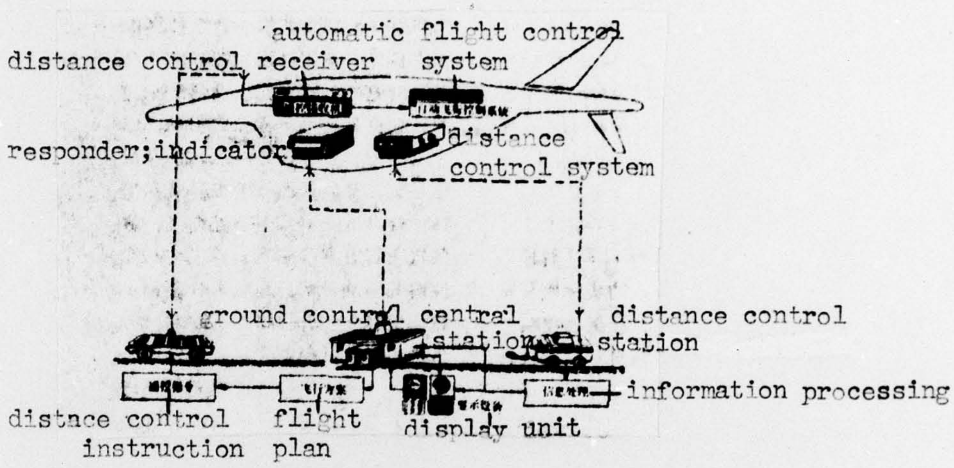


Figure 1 Sketch diagram of radio distance control principles

parts. The closed navigation return path is formed by data chain, which is transmitted through electromagnetic wave. The ground radar traces the pilotless aircraft by way of scanning return wave to determine the coordinate and flight track of the aircraft in the air. The information obtained from the airborne responder or indicator can strengthen the effect of this tracing. At the same time, the distance control system in the aircraft regularly issues every kind of parameter information of the aircraft to the ground, and the ground distance control station processes this information and sends it to the ground control central station. So the central station, based on radar and distance control information, can immdiately know the filght conditions of the pilotless aircraft. Then the central station, according to

the predetermined flight plan and the present control plan, issues distance control instruction to the pilotless aircraft to change or to correct its flight track, or to order it to complete some maneuvering flight and some special work (such as reconnaissance program, releasing interference). The airborne receiver, after having received the ground distance control instruction, inputs the information to the automatic flight control system to respond the ground instruction and control. The work like this continues till the completion of the mission. Finally the aircraft is guided to return to the predetermined airspace and ready to be recovered on the ground.

The distance control instruction can be decided by the navigation personnel in the central station, and it can also be decided by a computer. If it is by a computer, the predetermined flight plan is registered in the computer, and radra and distance control information are all sent to the computer. Thus it forms a closed cycle automatice navigation system of great circuit. One computer, in fact, can always control several pilotless aircrafts to carry out different missions.

A carrier aircraft, which is equipped with corresponding instruments, can use this method to guide pilotless aircraft, and the working principles are all the same.

2. Autonomous Navigation

When a pilotless aircraft deeply penetrates into enemy's territorial space to carry out its mission, on the one hand, it has been away from its ground base or its carrier craft, and beyond the functional distance of home distance control establishments; and on the other hand, it has to try

to aoid enemy's counter electronic devices,so it often uses an airborne autonomous navigation system to guide itself. The autonomous navigation devices which have been used by pilotless aircrafts are of the following different kinds.

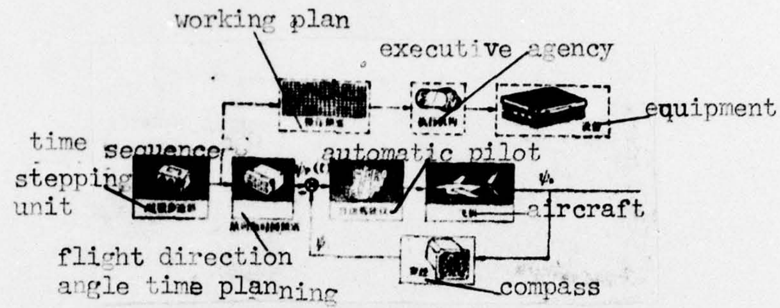


Figure 2 Sketch diagram of autonomous navigation principles on the basis of time sequence

1. Autonomous navigation on the basis of time sequence. The composition of the navigation system is indicated by the solid lines in Figure 2. The navigation is mainly to control the flight direction angle. It is almost the same as an ordinary aircraft determiningits flight direction by an automatic pilot. But the flight direction angle set by this method is not a constant value and it changes according to the flight time. For instance, a pilotless reconnaissance plane is predetermined to make survey over targets at A,B, and C three places behind enemy line (see Figure 3). The preset flight route is a curve line, and the pre-selected flight direction angles are $\psi_{D1}, \psi_{D2}, \psi_{D3}, \psi_{D4}$ and ψ_{D5}. These flight direction angles as voltage are regulated in the flight direction angle planning unit. The corresponding flight time t_i ($i = 1,2,3,4$) of each flight distance has, according to the preset flight speed (air speed),been computed out, also been adjusted by a timer in the time sequence unit. When it is carrying out its mission, the

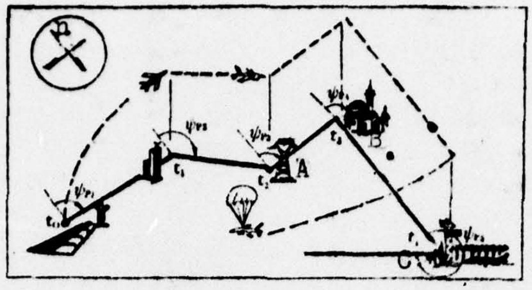


Figure 3 Example of flight direction angle control

distance control instruction (or program controller instruction) turns on the timer, and then the time sequence device and the flight direction angle time planning unit according to the flying time give the preset flight direction angle $\psi_D(t)$. When $t_0 \leq t < t_1$, $\psi_D(t) = \psi_{D1}$, and when $t_1 \leq t < t_2$, $\psi_D(t) = \psi_{D2}$. the real flight direction angle ψ_a can be found out by a gyromagnetic compass. Contrasting with ψ_{Di}, its error signal is sent to the latreal channel of the automatic pilot to control the aircraft to fly according to the predetermined flight direction angle.

This navigation is simple in equipment, but the accuracy of control is less reliable. It can make navigation error by the change of flight speed and wind interference. So it is always considered as an alternate plan of other ways of navigation.

2. Doppler radar automatic navigation. For the basic principles of Doppler radar navigation, see Sun Hui-fang's article in No.3, 1976 of this journal. Here we discuss some of the working principles of Doppler radar automatic navigation system.

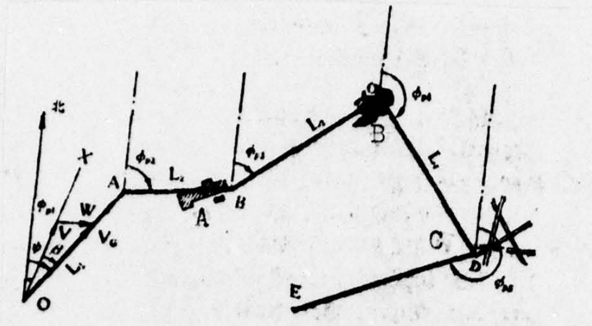


Figure 4 Example diagram of Doppler radar automatic navigation

The flight track of Doppler radar navigation is shown in Figure 4. The airborne Doppler radar can find out the ground speed (V_g) and crab angle (β) of a pilotless aircraft and send them to navigation computer after correcting the attack angle, and also is the flight direction angle (ψ), that can be found out by a gyromagnetic compass, sent to the computer. The computer then can find out the flight range (L) and the real flight range angle (ϕ_a). When the flight range information is sent to flight range stepping unit, the preselected flight range angle $\phi_p(L)$ comes out from the flight range setting unit. The preselected flight range angle $\phi_p(L)$ was put into the flight range angle setting unit in advance. $\phi_p(L)$ is contrasting with the actual flight range angle, which is known from the navigation computer, and its error signal is sent to automatic pilot. From Figure 4, it is known that the flight range angle is the integrate of flight direction angle ψ and crab angle β. So the automatic pilot, through an adjustment of flight direction angle of the aircraft can make actual flight range angle equal to the preselected flight range angle. Thus, after flying over each definite flight range, the aircraft makes the flight range angle change its

value once. For example, when L_1 = OA, $\phi_p(L) = \phi_{p1}$, and when L_2 = AB, $\phi_p(L) = \phi_{p2}$. The aircraft will make curvilinear flight along OABCDE, and make reconnaissance over A,B, and C three places one after the other.

The accuracy of this navigation plan is much greater than the other one mentioned above, because the navigation accuracy is not be affected by velocity change of the aircraft and the wind in the aur. But it will be affected by Doppler radar, the precision of gyromagnetic compass and the error made by navigation computer. Moreover Doppler radar can also be affected by the interference of enemy's electronic equipment.

3. Inertial platform automatic navigation. For promoting the precision of naviagtion, a pilotless aircraft of high speed and long continuous flight ability is often equipped with an inertial navigation system. This system uses inertial instruments and airborne digit computer to replace the Doppler radra system and can accurately determine the movement parameter of an aircraft along the earth coordinate system. It also uses flight range and flight range angle (track angle) to naviagte. A pilotless aircraft equipped with an inertial navigation system always has a small digit central processor. The preset flight plan and inertial survey information are all registered in the computer, which will issue control instruction after analysizing the flight plan and the survey information. Then the aircraft is controlled by the automatic pilot to fly along the preset route. At the same time, the central processor can register and process other instructions and make theequipment in the craft work harmoniously.

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